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MSC INTERNAL NOTE

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Survey of Satellite Reliability, Test and Checkout Programs

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FOREWORD

This report is a summary of reliability, test and checkout concepts that are practiced by the following agencies and aerospace contractors.

Jet Propulsion Laboratory
Pasadena, California

Hughes Aircraft Company
Culver City, California

Radio Corporation of America
Burlington, Massachusetts

Electronics Research Center
Cambridge, Massachusetts

Goddard Space Flight Center
Greenbelt, Maryland

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1.0 ABSTRACT

A survey of reliability improvement, test and checkout concepts was made to determine what the concerns and agencies have done in order to attain the levels of success that they have had in their various programs.

2.0 INTRODUCTION

With the emphasis on long-duration manned missions in the Manned Space Program, it has become apparent that we should examine and profit by the experience that has been gained in the long-duration unmanned programs. Some of the programs considered in this survey are as follows:

a) Ranger
b) Mariner
c) Tiros
d) Comsat
e) Surveyor
f) ATS
g) Intelstat
h) Nimbus
i) Syncom
j) OAO

The subjects of reliability improvement, test and checkout shall be broken out into 3 categories; (1) Component, (2) Subsystem, and (3) the system or total integrated spacecraft or satellite where applicable.

3.0 COMPONENT RELIABILITY AND TESTING CONCEPTS

3.1 VISUAL INSPECTION AND PARAMETER SCREENING

All organizations contacted, perform visual, dimensional and electrical parameter checking at the vendors. Hughes and JPL let the vendor do this at his plant, but also run these tests in-house on a 100% basis for each new procurement lot as well as on a sample basis (in-house) on regular hi-rel line items. Both Hughes and JPL stressed that this additional check is necessary to check on the vendors manufacturing line.

3.2 COMPONENT BURN-IN AND POWER AGING

Hughes subjects the components for the Comsat Project to 1000 - 1500 hours of burn-in on a 100% basis under maximum rated power and temperature conditions after the high reliability screening and acceptance tests. Intermediate readings are taken of all significant parameters to gain the information needed for their parameter degradation analysis program. The results of the extended burn-in or power aging are significant in that 28% of the components accepted by Hughes after passing the high reliability acceptance testing and 240 hours burn-in period are rejected for flight use by this power-aging method. GSFC on the ATS project (with Hughes the prime contractor) subjected the electronic components to a 1260 hour power-aging period after the 240 hour acceptance burn-in period.

JPL subjected the electronic components on the Mariner 64 project to 168 hours of burn-in with acceptance criteria being at qualification levels. JPL's present electronics specification (2750 General) calls for 240 hours of burn-in for acceptance. JPL is presently conducting life testing on electronic components after sterilization. The sterilization process being 6 cycles consisting of 36 hours at 145°C and 24 hours at 25°C for each cycle. After the sterilization period, the components (72,846 parts of 577 part types) are power aged for 10,000 hours. Although these tests are not yet completed for all types of components, one significant indication is that digital monolithic circuitry should be power-aged for at least 1000 hours.

Life Testing programs at JPL and Hughes have indicated that components previously thought to have almost infinite life times not only degrade but fail catastrophically at 7000 - 8000 hours. These results point out the need for a vigorous life testing program for future long-duration programs in order to detect the weak links in any system spacecraft so that the appropriate measures can be taken in the system design phases.

3.3 EVALUATION METHODS FOR RELIABLE PERFORMANCE

Input parameter variation and parameter degradation analysis have replaced the classical Go/No-Go type testing previously used. Go/No-Go testing limits the information gained to be valid at present, but can give no information useful in predicting future performance.

3.4 FAILURE RATE PREDICTING TECHNIQUES

Hughes component failure rate predictions are based on degradation analysis techniques and the data base is the results of exhibited results from their quality, screening, burn-in and life testing programs. JPL bases their failure rate calculation on the empirical data from the Ranger, Mariner, Surveyor and their life testing and sterilization programs. RCA proposed that failure rate calculation be based on time-dependent failure rate instead of the classical constant failure rate, thus making predicted reliability figures higher. Hughes and JPL agreed with this change in reliability philosophy, but stressed that this can only be done after the system or subsystem is thoroughly debugged through all design, testing and operational phases.

4.0 SUBSYSTEM RELIABILITY AND TESTING CONCEPTS

4.1 TEST EVALUATION METHODS

The physical processes of fabricating higher level assemblies from these high reliability and qualified components do not in many cases get the same level of attention as the individual components. Yet, these processes are the most difficult to control.

In order to proceed thru the fabrication processes with a high degree of confidence, stringent testing and power-aging must be imposed. Hughes with their degradation analysis approach handles the fabrication phase by monitoring every available parameter for drift thru all major phases of fabrication and assembly on their type approval (TA) systems as well as their flight systems.

JPL utilizes input parameter variation techniques in addition to degradation analysis to determine how the system will perform under off-nominal conditions, thus determining functional and operational performance limits.

4.2 ENVIRONMENTAL TESTING

Hughes and JPL subject both the type approval systems as well as the flight systems (FA) to rigorous vibration and Solar Thermal Testing (see Table 1 and 2). The stress levels on the type approval systems are approximately 150% of the worst case or acceptance levels. During these tests every available parameter is monitored to determine performance as well as to gather data for degradation analysis. The assembly and system environmental testing requirements that JPL and GSFC impose on the type approval and flight systems bring out three really significant tests; namely, the complex wave vibration temperature - vacuum and humidity tests (see Table 2). Acceptance test levels are the same as the worst case environmental expected during the mission.

4.3 SUBSYSTEM BURN-IN AND POWER-AGING

Burn-in and power-aging at higher levels of assembly such as at the subsystem level is conducted at simulated environments. This is done to determine how reliably these components which are power-aged are going to perform when joined together into a functional assembly operating under worst case expected conditions. JPL and Hughes stated that between 1200 and 2000 hours of operating time is accumulated on the system and spacecraft levels between the end of component burn-in and testing and time of launch. RCA emphasized that systems should undergo burn-in and power-aging in the same manner as the component testing. This is done to insure that no workmanship errors on fabrication-induced problems are present at the higher assembly levels. This is necessary to have continuity in confidence of reliability thru the various fabrication phases. (see Chart 2).

4.4 SUBSYSTEM LIFE TESTING

Life testing is performed to determine whether the subsystem's time to wear-out is longer than its required operational lifetime. This life testing is performed under as close to the real environment as simulated environments can feasibly be achieved. For the Mariner 64 Project JPL subjected the type approval systems to life testing with the goal being 6000 hours. A summary of the life testing results are given in Chart 2. The achieved lifetimes prior to test termination range from 3000 to 11,000 hours.

5.0 SPACECRAFT RELIABILITY AND TESTING

5.1 UTILIZATION OF ENGINEERING DEVELOPMENT MODELS

GSFC, Hughes and JPL utilize the prototype spacecraft for development testing such as form, fit and function in addition to utilization for overstress, environmental and vibration testing. JPL for the Mariner 64 project utilized the following spacecraft models for the purpose indicated.

a. STM structural control model for vibration and structural testing (see Table 3 for testing levels).

b. Temperature Control Model (TCM) for thermal environmental testing (see Table 3 for testing levels and duration).

c. Dynamic Test Model (DTM) for testing flight dynamics.

d. Separation Test Model (XTM) for launch vehicle-spacecraft interface separation testing.

e. Proof Test Model (PTM) for life testing of systems, form and fit of systems, EMI testing of TA and FA systems, verification and test of all internal cabling and GSE prior to interfacing with the flight spacecraft, development and verification of all test and checkout procedures prior to implementation on the flight spacecraft. The PTM is configured the same as the flight spacecraft so as to make valid testing correlation between the test spacecraft.

These models are utilized for qualification testing prior to acceptance testing of the flight spacecraft. The qualification levels are approximately 150% of the acceptance levels; with acceptance levels being at worst case expected conditions. (see Table 3)

5.2 TEST MONITORING AND EVALUATION METHODS

Both Hughes and JPL monitor every available parameter during test on the ground as well as during the flight. This is done for several reasons: (1) to perform engineering evaluation of spacecraft and system performance under actual operating conditions, (2) permit switching to a redundant operating mode upon indication of a malfunction or failure and (3) to gain information on which to base failure rates for future projects. JPL subjects their Test Article and Flight Article systems to parameter variation testing to gain a greater insight into systems operation under off-nominal conditions. This has proved very effective in predicting the systems behavior under flight conditions. Hughes does the parameter variation concept in the same manner as JPL, but also for the purpose of degradation analysis. Degradation analysis has proved very effective in detecting and predicting malfunctions and failures. This method requires a very thorough instrumentation and testing system as well as the use of analyzing parameter trends, and is inherently much more effective than Go/No-Go testing.

Both JPL and Hughes utilize as much as possible the same test/checkout equipment and personnel thru all phases (factory thru launch) in order to minimize possibilities of error, both operator and equipment wise, as well as to provide a consistent data base on which to evaluate the spacecraft and system performance.

Since the Proof Test Model (PTM) is configured the same as the flight spacecraft, the launch area and mission operational procedures and interfaces are developed prior to implementation on the flight spacecraft.

The personnel at GSFC emphasizes two very important points that must be made; (1) the subjecting of a flight prototype or (proof test model) S/C to the full range and variety of testing phases, particularly the thermal vacuum and vibration testing at 50 percent safety factor conditions and (2) the flight spacecraft be subjected to the complete range and variety of testing environments, but at a reduced stress level in order to "wring out" the spacecraft as thoroughly as possible.

6.0 SUMMARY

The following is presented in summary as the more important findings regarding the reliability, test and checkout practices:

a. Specified and imposed more rigorous parts screening, test, burn-in and life testing programs at the component level.

b. Utilized all possible and feasible access points into and out of the spacecraft systems and performed parameter variation type testing and performed degradation and trend analysis for failure detection and prediction.

c. Developed and utilized "Type Approval (TA) subsystems for sustained operational performance and life testing at maximum environmental test conditions. These tests should be performed at the earliest possible time so that improvements can be incorporated into the flights systems with least impact.

d. Developed, implemented and utilized the "PTM" or "House" spacecraft and systems and enforced strict configuration control performed:
   - Life testing on a totally integrated basis in worst case simulated test environments.
   - Verification of all electrical, hardware, instrumentation and checkout interfaces prior to utilization on the flight spacecraft.

e. Determined reliability, redundancy, and maintainability requirements and performed the necessary trade-offs prior to the initial design phases for all subsystems, systems and the spacecraft and implemented at an early time into the design phases.

f. Developed the test and checkout concepts and implemented into the earliest initial design phases instead of performing on an "after thought" basis.

g. Utilized as much as possible, the same checkout, equipment, procedures and personnel thru all ground testing phases.

h. Developed a strong checkout and environmental testing program, especially the thermal-vacuum, humidity and vibration testing phases.

i. Testing limited to those facilities that have been thoroughly screened and approved by cognizant representatives of engineering and quality assurance. Thorough indoctrination of vendor and testing personnel in applicable test specification, standard operating procedures and reporting systems is a prerequisite to reliable test performance and data from vendor and testing sources.

Table 1 - Assembly Level Environmental Test Requirements

Test	TA Test Level	FA Test Level
Bench Handling	Free fall corner drop	N. A.
Drop Test	Height variable to weight	N. A.
Transportation Vibration	1.3 g 2-35 cps 3.0 g 35-48 cps 5.0 g 48-500 cps	N. A. N. A. N. A.
Explosive Atmosphere	Fuel and air during assembly operation	N. A.
Humidity	75% humidity and varied temperature	N. A.
Shock	5 200 g, 0.7 ± 0.2 milli-second pulses, 3 axes	N. A.
Static Acceleration	± 14 g, 3 axes 5 min	
Vibration Low Frequency (all assemblies)	± 1.5 in., 1 to 4.4 cps 3 min 3 g peak from 4.4 to 15 cps	N. A.
Complex Wave (assemblies 10 lb)	16.4 g rms noise 180 sec	9.0 g rms noise 6 sec
	5.0 g rms noise plus 2.0 g rms sine, 15-40 cps 9.0 g rms sine, 40-250 cps 600 sec	3.0 g rms noise plus 1.5 g rms sine, 15-40 cps 6.0 g rms sine, 40-250 cps 200 sec
	*4.5 g rms sine, 250-2000 cps	**3.0 g rms sine, 250-2000 cps
		9.0 g rms noise 6 sec
Vacuum/Temperature	-10°C (+14°F) 4 hours +75°C (+167°F) 12 days 10^{-4} mm Hg	0°C (32°F) 2 hours 55°C (131°F) 40 hours 10^{-4} mm Hg
Thermal Shock (for external assemblies)	+75°C to -46°C (167°F to -50°F)	N. A.

* 9.0 g for assemblies $<$ 10 lbs.

** 6.0 g for assemblies $>$ 10 lbs.

JPL - MARINER 64

Table 3 - System Level Environmental Test Requirements

Test	TA Level	FA Level
SPACE SIMULATOR Part I - (Systems Validation)Launch through Encounter & Playback Part II - (Temp. Control Verification)	10 days at 10^{-5} mm Hg (or less) 108 hrs at 30 to 134 watts simulated solar intensity	250 hrs at 10^{-5} mm Hg (or less) 134 hrs at 30 to 134 watts simulated solar intensity
VIBRATION-SINUSOIDAL	Roll Axis 5-15 cps, 1.5 g rms 1.6 min 15-450 cps, 1.5 g rms 8.3 min 450-800 cps, 5.0 g rms 0.8 min 800-2000 cps, 10.0 g rms 1.3 min (and reverse sweep) 3 Lateral Axes 5-150 cps, 0.75 g rms 5.1 min 150-450 cps, 1.25 g rms 1.5 min 450-800 cps, 5.00 g rms 0.8 min 800-2000 cps, 10.00 g rms 1.3 min (and reverse sweep)	Roll Axis 20-200-20 cps, 0.5 g rms 3 1/4 min. 2 Lateral Axes 20-200-20 cps, 0.5 g rms 3 1/4 min per axis.
VIBRATION - NOISE	Roll Axis & 3 Lateral Axes Shaped spectra, 18.1 g rms overall 550-2000 cps, 0.2 g^2/cps 3.0 min 3 db/octave roll-off below 550 cps	Roll Axis & 2 Lateral Axes Shaped spectra, 10.7 g rms overall 550-2000 cps, 0.07 g^2/cps 1 min 3 db/octave roll-off below 550 cps
VIBRATION - TORSIONAL	2 69 cps pulses, 205 rad/sec^2 0.14 sec 20-150-20 cps 12.86 rad/sec^2 6.0 min 50-150-50 cps 154 rad/sec^2 11.0 min	N. A.
ACOUSTIC	Approx. 142 db shaped spectrum 90 sec	N. A.
SHOCK	Shroud V-Band Release Firing S/C Separation & V-Band Release Firing All S/C Pyrotechnics Fired	N. A. N. A. All S/C pyrotechnics fired.
ELECTROMAGNETIC INTERFERENCE-RF SUSCEPT ABILITY	Launch Complex RF Agena Telemetry RF C-Band Beacon	Launch Complex RF Agena Telemetry RF C-Band Beacon

Table 2. Subsystem Environmental Test Summary

Environment	No. of Subsystems in Test *	Total Items in Test	Total Failures	Failure Rate (percent)
<u>TA Tests</u>				
Bench Handling	22	39	0	0
Package Drop	25	39	0	0
Trans. Vib.	27	85	0	0
Humidity	31	51	5	9.8
Expl. Atmos.	18	19	0	0
Shock	49	116	3	2.6
Acceleration	46	89	0	0
Lo Freq. Vib.	51	90	6	6.7
Complex Wave Vib.	54	154	24	15.6
Vac/Temp	50	95	19	20.0
Thermal Shock	26	28	1	3.6
<u>FA Tests</u>				
Vac/Temp	41	310	28	9.0
Complex Wave Vib.	49	538	26	4.8
Temp	2	21	1	4.76
<u>TOTALS</u>				
TA Tests		805	58	avg 7.2
FA Tests		869	55	avg 6.33
		1674	113	avg 6.86

The limited number of problems encountered during spacecraft acceptance testing and the successful launch and midcourse maneuver of Mariner IV attest to the adequacy of the systems level TA and subsystem TA and FA testing. A total of 83 design changes were documented. Of the 83, 39 originated at the TA level, 14 at the FA level, and 30 during other environmental tests. The majority of the changes instituted during FA level testing were due to schedule slips which necessitated running FA tests prior to or concurrently with TA tests. On an ideal schedule the TA testing would have demonstrated the need for the design change before flight hardware was fabricated.

* Some subsystems were granted waivers and were not required to meet the environment.

BURN-IN & POWER AGING

PRACTICES

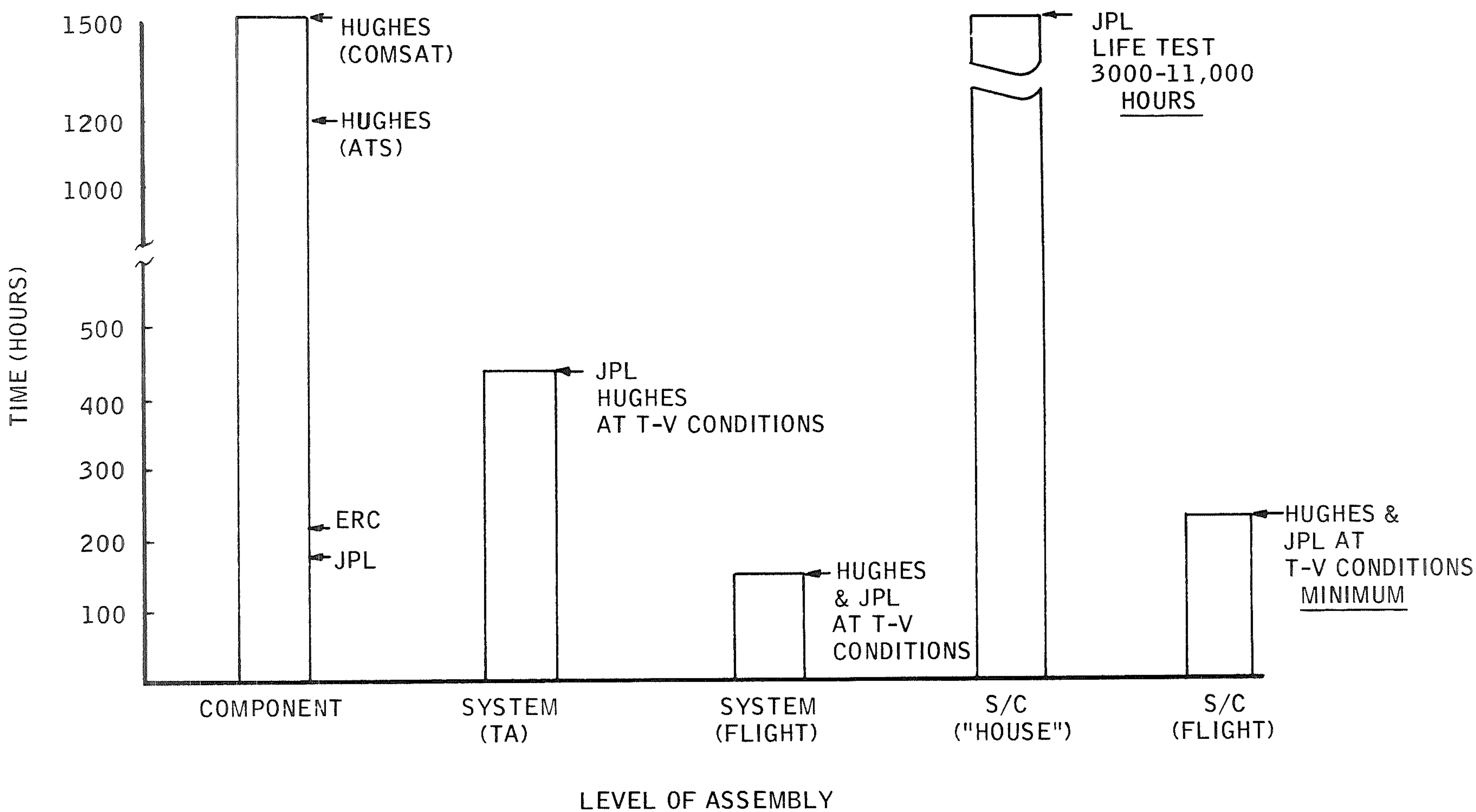
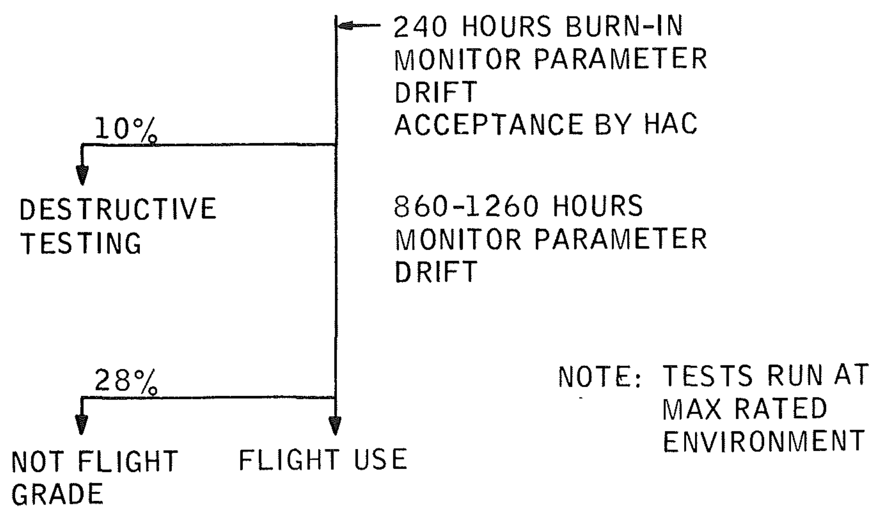


CHART I

COMSAT PROJECT(HUGHES)

COMPONENT (HI-REL)
- VISUAL INSPECTION
- PARAMETER SCREENING



JPL LIFE TEST RESULTS (TA SYSTEMS)

MARINER 64

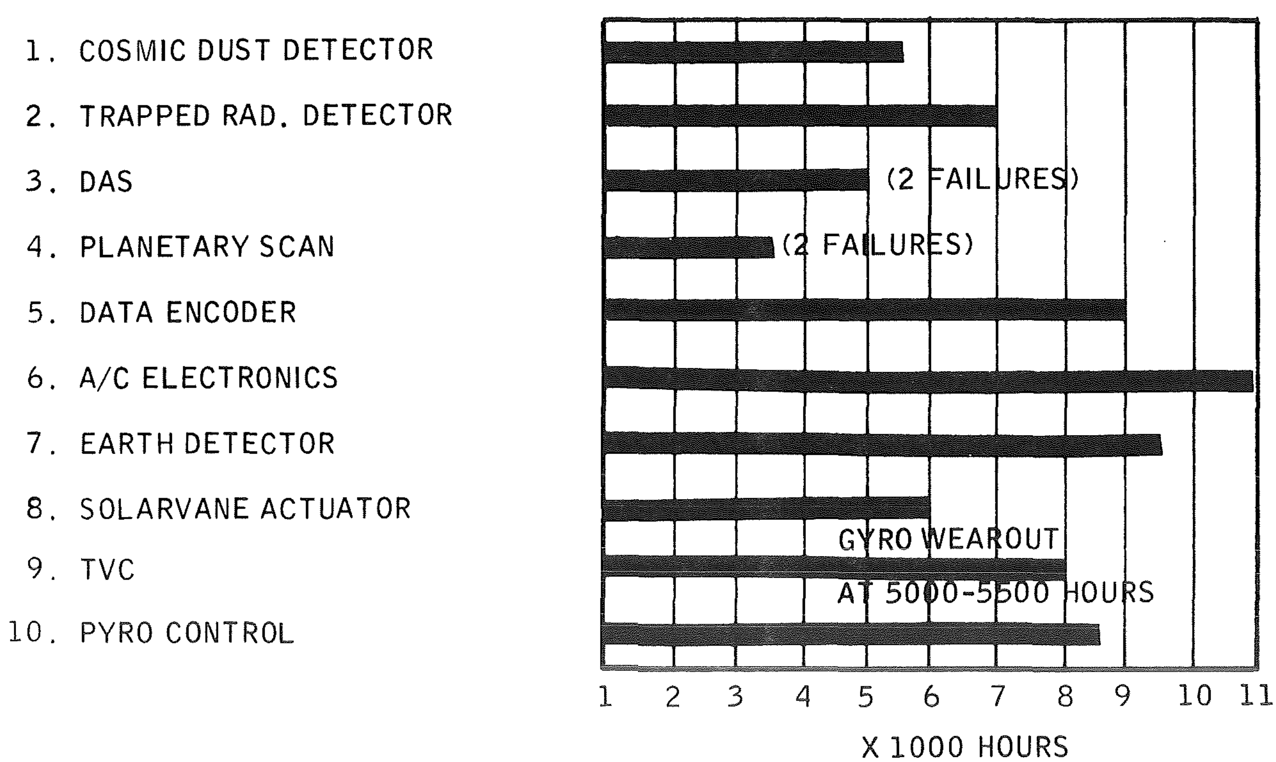


CHART II

RESULTS OF GSFC
TESTING (64 S/C)

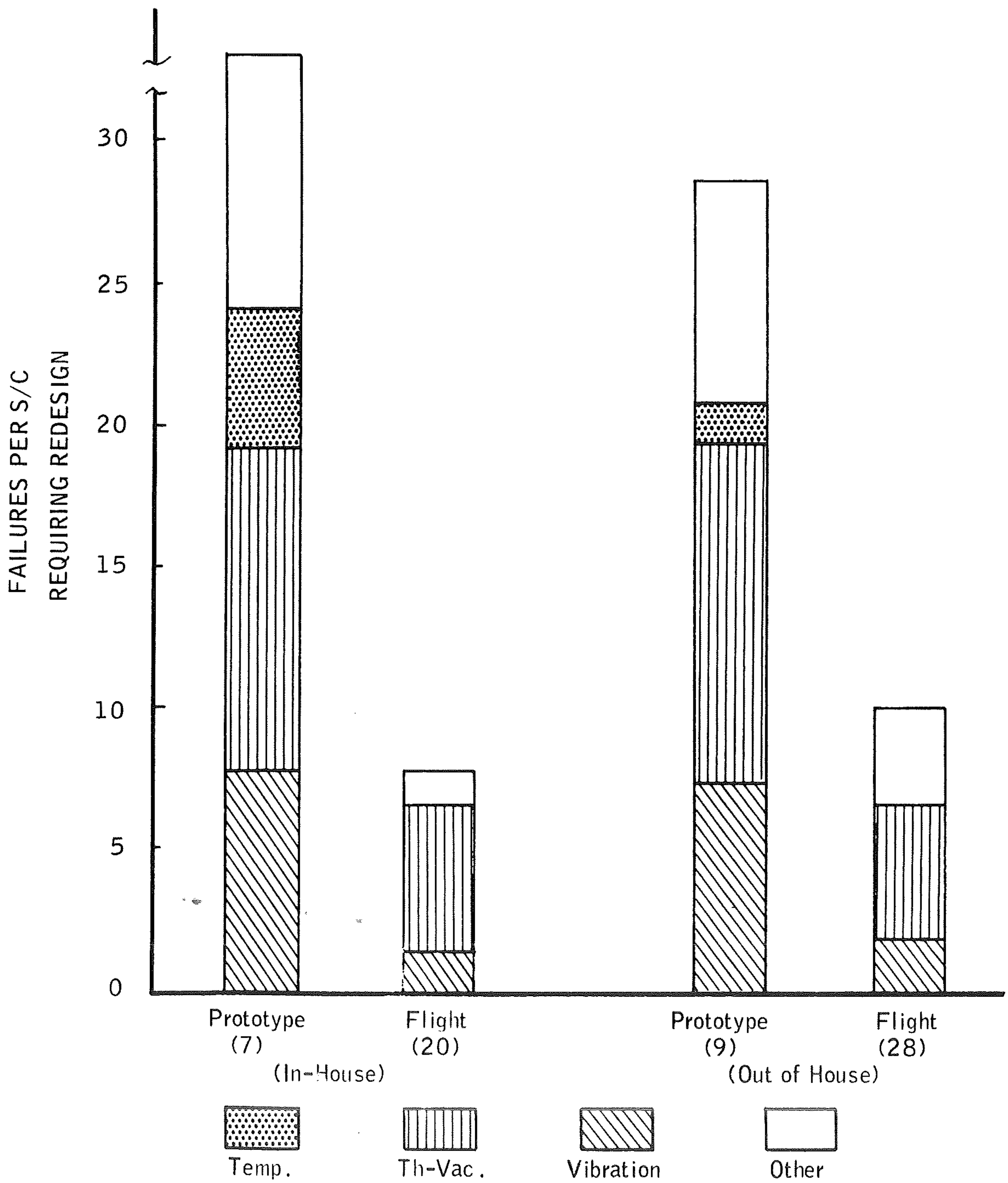


CHART III